Assessment of flood risk reflecting regional characteristics of urbanization in South Korea

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Abstract

In recent decades, extreme weather events including heavy rainfall and flash floods have increased all over the world. For reducing the likelihood of flood events and making a resilient society, it has become important to understand the interaction of flood occurrences and regional characteristics because damage can vary depending on the spatial and temporal variation. In this study, we examine the interaction of flood risk and regional characteristics on the temporal and spatial (urban and rural) context by analyzing flood property losses in Korea from 2000-2014. Specifically, the study period is divided into three parts with five-year intervals in an effort to better understand how to change the influence of the hazard, topography, land-use, capacity, and socioeconomic factors as well as urbanization on property damage over time.

The findings suggest that 1) some variable are continuously significant to flood property damage during 15 years, 2) there is a change of effects on flood property damage not only significance but direction in some variables over time, and 3) geographic localities characterized by the degree of an area's urbanization have a different pattern of flood risk in terms of land use and socioeconomic factors. In particular, heavy downpours that occur in a short time can generate much bigger damages than precipitation which accumulates over a longer time. And mountainous areas contain a lot of steep slope-land are more vulnerable to flood risk than floodplain area, but the land use characteristics of floodplain area is important to assess the flood risk. Empty houses variable is only significantly associated with flood damages in rural area.

This study provided the evidence that the trends and changes of flood risk during the last 15 years by examining significant factors which associated with flood property losses on the temporal and spatial (urban and rural) approach. In this regard, the findings are expected to help urban planners and disaster managers to develop regionally appropriate methods for flood damage reduction.

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Ⅰ. Introduction

Flooding is the most frequent natural hazard in Korea that causes severe damage. According to data from the National Disaster Information Center, floods comprised 42 percent, of a total of 409 cases of natural disasters between 1990 to 2014 in Korea. Floods have occurred an average of 7 times a year since 1990. In addition, of all natural desasters, floods cause the most victims (67%) and human losses (57%) including death, injury and missing people. Loss of property due to floods was more than 2,659 billion won over 25 years.

In recent decades, extreme weather events including heavy rainfall and flash floods have increased all over the world (Jha et al, 2012). Structural changes in society deriving from urban growth and industrial development, have led to changes in flood mechanisms. Seoul and Busan metropolitan cities in Korea have suffered damage from flash floods caused by one or two days of sudden, heavy downpours in 2011 and 2014. The heavy downpour flooded large areas of the cities, especially the low-lying districts, causing traffic jams, landslides and blackouts. As a result, dozens of people died or were seriously hurt. Those incidents are examples of how flood frequency and intensity have become more unexpected now.

Facing an increasing number of extreme rainfall events, it is essential to investigate the relationship between hazard and damage occurrence. If we know how to flood occurs and what makes it more dangerous, floods can be controlled by constructing structural measures – dam, levee, barrier, sandbags and so on – and tightening the non-structural techniques – flood monitoring, warning system, watershed management, and so on–. Furthermore, for reducing the likelihood of flood events and making a resilient society, it has become important to understand the interaction of flood occurrences and regional characteristics because damage can vary depending on the spatial and temporal variation. Research on flood risk assessment indicates the importance of analysis which considers regional characteristics (Lee et al., 2007; Lee et al., 2013; Jung et al., 2014). Despite its importance few quantitative studies exist on the temporal and regional approach to flood risk. The lack of comparative analysis reflecting spatial and temporal variation make it hard to identify what factors are significantly associated with flood property losses with the temporal and spatial changes in Korea.

In this study, we examine the interaction of flood risk and regional characteristics on the temporal and city classification (urban and rural) context by analyzing flood property losses on the scale of Si (City), Gun (County), Gu (District) in Korea from 2000-2014. Specifically, the study period is divided into three parts with five-year intervals in an effort to better understand how to change the influence of the natural environmental, of built environmental and of socioeconomic factors on property damage over time. And with models predicting total flood property damage, all of the cities were categorized based on the degree of an area's urbanization for specific assessment reflecting regional flood characteristics.

In short, the objectives of this study were 1) to identity whether there are trends and changes of flood risk during the last 15 years; 2) to examine whether geographic localities characterized by the degree of an area's urbanization have a different pattern of flood risk; and 3) to investigate what factors are significantly associated with flood property losses on the temporal and city classification (urban and rural) approach. Our investigation of flood risk contains four parts. First, through a literature review, we examine the theoretical concept of flood risk and its relationship with urbanization. Second, we discuss the research design in earnest, the scope and procedure, variables, and statistical methodologies for analysis. Third, the results of our research are presented. Flood property damage is analyzed with 6 components of variables using multiple linear regression: urbanization, hazard, topographical, land use, capacity, and socioeconomic factors. Fourth, we describe the implications and limitations of our research, and suggest future study.

Ⅱ. Literature Review

2.1 The determinants of flood damage

From climatological to multiple factors

Flood is one of the most significant climate related natural hazards in terms of the number of affected people and economic losses (Zhang, 2013; Kellens et al., 2011; Abhas et al., 2011). In spite of its large impacts, before the 1990s, there is a noticeable gap in terms of floods between the climatologists view and the views of the policy makers (Pielke and Downton, 2000). The climatologists regard "flood" as hydrologic floods, while it is considered as a damaging floods to policy makers (Pielke, 1999; Pielke and Downton, 2000). This gap brings on limitation to understand the causes of flood damage because the degree of damage is not always determined as a result of hydrologic floods.

Several literatures attempt to explain a relationship between climatological flood and flood damages (White et al, 1958; Changnon, 1980; Changnon and Demissie 1996; Pielke and Downton, 2000). Generally, the larger amounts of precipitation lead to the higher flood damage (Park et al, 2011). Researchers find a strong relationship between meteorological factors and flood damage through the empirical research. But, they also suggest that the degree of flood damage varies by region in the same rainfall intensity because flood is interrelated with multiple factors, such as not only climatological factor but geographical, topographical, built environmental, social and socioeconomic factor (Pielke and Downton, 2000; Andjelkovic, 2001; Brody, 2007; Cutter, 2008; Zahran, 2008).

Geographical and topographical factors

The geographical and topographical factor are related with "Exposure" matter. Exposure is normally defined as the values and people in the threaten area (Kron, 2003). People who live in low-lying area are in danger of flooding when rivers exceed the capacity of natural or flood migration structures because water overflows the stream banks and spills out into floodplain areas (FEMA). Thus, the development of low-lying area makes it easy surface water to be collected before it reaches to water bodies or drainage system (Shin, 2011). In mountainous area, flooding can be occurred rapidly with high velocity because they have narrow and steep valleys. Also, these floods bury homes and sweeps away people and cars by generating landslide. The large amount of debris caused by flood is another problem to response and recovery in this terrain.

Built environmental and urbanization factors

The research on the relationship of built environment or urbanization factors in producing damaging flood has been ongoing for many years (Mileti, 1999; Lundgren, 1999; Cutter, 2003). Through decades of studies, we understand that flood damage is associated with industrial and technological development and human civilization. For example, researchers suggest that population growth increases a regional flood vulnerability by change the land use (Changnon, 2000; Pielke and Downton, 2000). Actually, surface water run-off which is the most frequent flood in urban area can be occurred if the amount of precipitation exceeds the water evaporation and infiltration capacity of the soil (FEMA, Shim et al, 2008; Shin, 2011). Owing to the fact that population growth commonly generates the increase of impervious area and development of floodplain for building construction and road pavement, it raises flooding problems by reducing infiltration capacity of the soil (Changnon, 1996; Lee et al., 1991; Kang, 2011; Shim, 2012; Lee, 2015).

These results imply human activities can act as a factor of damage, but it opens a chance to control damages by applying proactive urban planning and management (Lee, 2015). It means that engineering and political solutions such as land-use planning, code enforcement, dam, levee, and insurance can reduce damage from natural disaster (Burdy et al, 1998; Kunreuther, 2006; Brody et al, 2007; Zahran et al, 2008; Shim et al, 2012; Neumayer et al, 2014). Neumayer et al (2014) note that disaster damage can be reduced by implementing mitigation and preparedness policies such as construction of regulations, rules, dykes and dams. Thus, urbanized countries and cities try to prevent disaster risk by investing on both infrastructure facilities and policies. As a result, the occurrence pattern of flood damage between high-developed area and low-developed area become different.

Social and socioeconomic factors

In the disaster literature, the socioeconomic factor used to examine how economic status and activity affects to susceptibility or vulnerability to the damage. There are different points of views in terms of a relationship between income and damage. Kunkel, Andsager and Easterling (1999) note that flood property damage can be increased in high income due to the increase of their economic values. On the other hand, Toya and Skidmore (2007) suggest that high-income countries is suffered relatively less damage than low-income countries because the high-income countries can secure an enough recovery cost and invest on both infrastructure facilities and policies to prevent disaster risk. Although the relationship between income and disaster damage is still complex and not fully understood, it is distinct that an effect of natural hazard can be different with socioeconomic status. Similarly, in many studies, researchers find that economic status are highly related with social matter (Cutter, 2003; Brody, 2007; Zahran, 2008; Yoon, 2012). Most of second class citizen such as disabled people, a one-parent families, elderly, part-time employees and others have difficulties in lives due to low-income. They are more likely to be vulnerable in flood situation because the social vulnerability interacts to produce the place vulnerability (Cutter, 2003). Moreover in case of disabled people and elderly, they take a longer time to move out of danger area.

In regional approach, aging is one of socioeconomic matters. In aging society, the financial cost to government is likely to escalate because this phenomenon leads to increase in the dependency ratio, lower rates of economic growth, and superannuated and unoccupied facilities. Also, community is more hard to respond to and recovery from disaster situation due to the lack of human and financial resources.

2.2 Researches on the flood risk in Korea

As indicate above, flooding is generated as a result of the interaction among multiple factors. The important thing is that both the degree of flood damages and the influence of variables to flood risk are continuously changed because climatological, geographical, topographical, built environmental, social and socioeconomic factors are changed with the spatial and temporal variation. It means that the result of flood risk assessment depends on how to compose the temporal and spatial boundaries. Thus, it is hard to directly apply methodologies used for other study area because the effect of floods such as intensity, frequency, and damages varies in different regions and different conditions (Andjelkovic, 2001; Jung et al, 2014).

Based on this view, we check recent studies regarding disaster damage analysis in Korea. Most of studies attempt to examine the relationship between property losses and parameters affecting to damages on the regional approach. Kang and Lee (2012) analyze flood vulnerability by using a combination of vulnerability indexes – exposure to climate, sensitivity, and adaptive capacity – and fuzzy logic model in Seoul in 2010. Jung and Heo (2014) attempts to statistical analysis for identify the time trend of economic damage from natural hazard in Gangwon province in Korea. By using panel data about GRDP, population and area, they find that an increase of income makes society more vulnerable to natural disaster over the period 1981-2012. Shin (2011) indicated influence variables on inundated area by comparing regression results of two different floods occurred in 2010 and 2011 in

Seoul. In this study, an inundated area is significantly associated with low-lying area under river bed height and rainfall intensity. In case of residential and commercial area and impervious area are statistically significant each in 2010 and 2011. Time trend analysis is effective to reflect the change of variables in certain area. However, Jung and Heo (2014) doesn't consider specific variables due to the data availability, and Shin (2011) uses inundated area occurred in different years for generalizing significant factors not for identifying time trends. Also, those two studies hard to apply on the nationwide model because they focused on certain local area for analysis.

On the other hand, Choi and Seo (2013), Shim and Kim (2012), and Yoo et al (2013) try to analyze reasons of disaster property damages through land use and topographical characteristics. Choi and Seo (2013) assess the impact of factors related with urban characteristics on damages cause by natural hazard using the time series data during 1988-2010 in South Gyeongsang province. They indicate the urbanization density and city budget are positively associated with property damages. Shim and Kim (2012) present the effect of diverse land-use characteristics on the property damage caused by natural disaster in Seoul, Incheon, and Gyuonggi area. They find that the increase of impervious surface and industrial area are positively significant with total natural disaster damage. Those studies are valuable to propose some effective mitigation ways regarding urban planning, but they have limitations on study area and variables because these study focused on the effects of land-use and topographical factors in urban area. They not considered rural characteristics and climatological, social and economic factors affecting to disaster damage.

Several studies conduct to assess flood vulnerability using developed flood vulnerability index. Lee et al (2010) assess five watershed area for flood vulnerability with vulnerability indexes and climate change scenario indexes, and Jung et al (2008) also evaluate a relative flood vulnerability of watershed. But those studies select independent variables which composed of structural and geographical variables, so they fail to consider an effect of socioeconomic factors. Jung et al (2014) estimate flood risk index (FRI) in Korea considering the regional flood characteristics based on the Delphi survey to water resources experts. They find that natural and social factors are more influential than administrative, economic, and facility factors to Korea.

Most of studies we reviewed have been limited to a certain local area and certain year, so there are few studies which evaluate regional flood risk at national level considering temporal variation. Besides, the lack of comparative analysis reflecting urban and rural characteristics make it hard to identify how the mechanism of flooding is different between urban and rural in Korea. Thus, in this study, we try to examine the influence of variables and their trends in the specified time interval during 2000-2014 at national level. Also, considering the difference of flood mechanisms between urban and rural, we examine what are critical factors to generate flooding in urban and rural by categorizing all cites using the degree of an area's urbanization.

Ⅲ. Research Design

3.1 Scope and procedure

The geographic scope of this study is all regions of South Korea. We collected indicators at the sigungu level. Si (City), Gun (County), Gu (District) are the lowest administrative divisions in Korea. Although alternative spatial units such as Eum, myeon and dong (tracts and block groups) are more specific, they generally have no planning authority. Also there is a limitation of data availability. The flood event is recorded at the sigungu level, or higher in Korea.

For the reliability of data, all variables including dependent variables, are based on the official material provided by the government. The Property losses data was compiled for the period 2000-2014. Meanwhile, independent variables were collected based on the years2000, 2005, and 2010. With the comparison of total models in different time units, we also examined the critical factors in generating flooding in urban and rural areas.

For regional specific assessment, we sorted all cites into three different groups by the degree of an area's urbanization (see figure 1). An urban group consists of cities which have over 80 percent urbanized land. The number of cities in the urban group changed from 72 to 74 in 2005 and from 74 to 76 in 2010. Contrariwise, around 110 cities which have under 20 percent of urbanized land were classed as rural. The number of cities in the rural group also changed, from 115 to 107 in 2005, and from 107 to 106 in 2010. Every other developing region is excluded in regional comparison analysis.

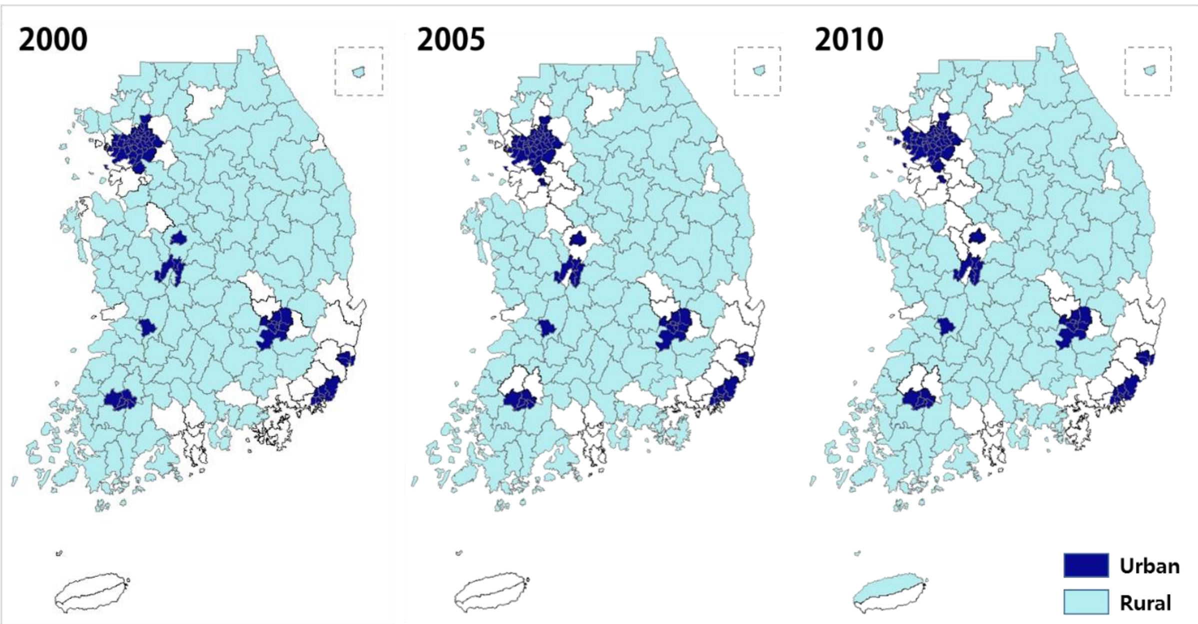


Figure 1. Spatial distribution of urban and rural area

We assume that the significant variable would be different between urban and rural areas. This assumption starts in recognition of 1) the different mechanism of flooding between urban and rural, and 2) the intimate connection between independent variables - Every variable has its own unique meaning and specificity, but, they share a spatial characteristic which inheres in them at the same time. In particular, socioeconomic and built environment variables are linked closely to urbanization (Changnon, 1996; Lundgren, 1999; Lee, 2015).

3.2 Measurement

Dependent variable

The dependent variable, property losses, is derived from the yearbooks of disaster provided by the Ministry of Public Safety and Security. This database consists of a county-level inventory of damages including the number of casualties and victims, inundation area and several kinds of property losses generated by natural hazards such as flood, typhoon, heavy snow, blizzard, strong wind and so on. The property damage variable is measured as the annual total economic loss caused by flood events. There are several criteria for collecting dependent variables, as follows:

First, we used the flood damage data set for the during 15 years between 2000-2014compiled by the Ministry of Public Safety and Security. Second, a few regions have been integrated into the surrounding area by administrative district reorganization during the study period. So, all regions are rearranged based on the 2010 administrative district criteria in order to maintain a consistency of data. For example, Masan-si and Jinhae-si data is combined with Changwon-si data and Sejong-si data is replaced by Yeongi-gun data. Third, this variable is normalized by two factors – inflation and population. In general, normalized disaster damage can be calculated with GDP deflator, population and wealth per capita (Pielke and Landsea, 1998; Pielke et al., 1999, 2008; Vranes and Pielke, 2009; Barthel and Neumayer, 2012). The typical equation of this conventional approach is as follows:

$$\text{Normalized Damage}_t^s = Damage_t \times \frac{GDP\ deflator_s}{GDP\ deflator_t} \times \frac{Population_s}{Population_t} \times \frac{Wealth\ per\ capita_s}{Wealth\ per\ capita_t} \quad (1)$$

where s is the (chosen) year one wishes to normalize to and t is the year in which damage occurred (Barthel and Neumayer, 2012). In this study, with 2010 as a base year, property damage is adjusted using the Gross Domestic Product (GDP) deflator, and then normalized by the total population of each

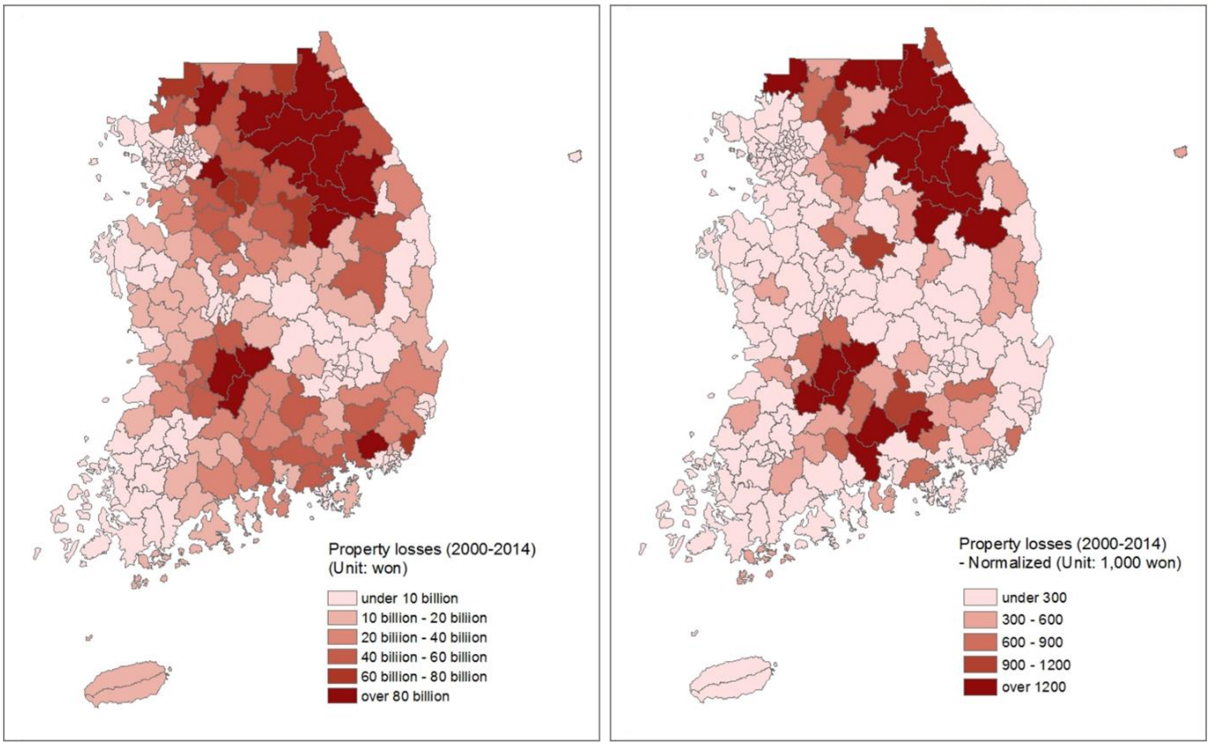


Figure 2. Flood property damage (left) and normalized one with population (right)

region. Fourth, flood related property losses variables are log transformed to compensate for its non-normality. Figure 2 shows the spatial distribution of total flood property damage and normalized flood property damage with population over 15 years (2000-2014). The darker parts reflect higher values. Before property damage was normalized, the north-east inland area (mostly Kyunggi and Kangwon province) and south inland area (mostly north of Jeolla and south of Kyungsang province) recorded higher property damage than other regions. In this map, metropolitan cities record lower property damage despite their high income. In the normalized map, higher property damaged areas are more distinct.

Independent variable

To examine the flood risk, we collected meteorological, geographical, built environmental, socioeconomic factors based on the literature review (see Table 1 for summary of variable operations and see Table 2 for descriptive statistics of variables). Total 21 variables were collected considering the periodical measurability and predictability of data at Si (City), Gun (County), Gu (District) scale and we categorized those variables as 6 components based on their characteristics.

Table 1. Variable operation, source and expected effect for dependent variable

Component	Variable name	Variable operation	Data source	Effect
Dependent Variable				
Flood property damage		Inflation adjusted (2010 base year) property damage caused by flood events during 2000-2014	Yearbooks of disasters	
Independent Variable				
Urbanization	Urbanized area	The degree of an area's urbanization (Urbanized area/Total area)	Statistics Korea	+
	Urban population density	Population density in urbanized area		+
Hazard	Flood frequency	Total number of flood events	Yearbooks of disasters	+
	Precipitation-1	Average of daily maximum precipitation during flood occurrence period	The Meteorological Administration	+
	Precipitation-2	Average of total accumulated precipitation during flood occurrence period		+
Topographical	River area-1	A density of main stream in region (%)	SGIS – DEM and National Hydrography Dataset (http://sgis.kostat.go.kr)	+
	River area-2	A density of branch and small river in region (%)		+
	Floodplain area	A density of floodplain area in region (%)		+
	Steep slope-land	A density of steep slope-land in region (%)		+
Land use	002 Impervious area	A density of impervious area in floodplain (%)	EGIS – Land cover (https://egis.me.go.kr)	+
	002 Farmland	A density of farmland in floodplain (%)		+
	610 Impervious area	A density of impervious area in steep slope-land (%)	SIS – Soil data (http://soil.rda.go.kr)	+
	610 Farmland	A density of farmland in steep slope-land (%)		+
	Denuded forest land-1	A density of denuded forest land - unwooded (%)	The Korea Statistical Information Service	+
	Denuded forest land-2	A density of forest land covered with road, stream, rock and others (%)		+
Capacity	Financial independence rate	Average of annual financial independency rate		-
	Volume of retarding basin	Total volume of retarding basin	Ministry of Environment	-
	Sewerage system supply rate	The ratio of sewered population (%)		-
Socio economic	Old buildings	The ratio of old buildings over 30 years (%)	Statistics Korea	+
	Empty houses	The ratio of empty house (%)		+
	Disabled	The ratio of registered disabled (handicapped) (%)		+

Table 2. Descriptive statistics of variables

	2000				2005				2010			
	Min	Max	Average	SD	Min	Max	Average	SD	Min	Max	Average	SD
Property damage *	0	219431093	8872202	18863061	0	580448367	12675819	51339450	0	61941095	4464510	9614276
Log_Property damage *	-5.6	7.7	2.9	2.5	-5.2	9.7	2.8	2.8	-6.3	7.1	1.8	2.5
Urbanized area	0	100.0	41.5	41.9	0.340	100.0	43.5	41.7	0.530	100.0	44.0	41.7
Urban population density	0.0002	0.029	0.004	0.006	0.000	0.029	0.004	0.006	0	0.029	0.004	0.006
Flood frequency	0	8.0	3.6	1.8	0	13.0	3.3	2.2	0	16.0	4.5	3.3
Precipitation-1 (daily max)	0	282.9	118.9	48.8	0	274.7	108.0	60.6	0	315.1	127.5	64.5
Precipitation-2 (accumulated)	0	489.1	248.7	92.2	0	632.4	226.4	129.2	0	690.2	240.3	113.5
River area-1 (%)	0	0.214	0.015	0.030	0	0.214	0.015	0.030	0	0.214	0.015	0.030
River area-2 (%)	0.002	0.056	0.023	0.011	0.002	0.059	0.023	0.012	0.002	0.058	0.022	0.012
Floodplain area (%)	0	76.5	20.1	18.3	0	76.5	20.1	18.3	0	76.5	20.1	18.3
Steep slope-land (%)	0	33.3	7.5	5.7	0	33.3	7.5	5.7	0	33.3	7.5	5.7
002 Impervious area (%)	0	98.0	21.8	24.3	0	98.0	21.8	24.3	0	98.0	21.8	24.3
002 Farmland (%)	0	80.7	33.8	22.8	0	80.7	33.8	22.8	0	80.7	33.8	22.8
610 Impervious area (%)	0	92.6	2.7	8.5	0	92.6	2.7	8.5	0	92.6	2.7	8.5
610 Farmland (%)	0	27.3	3.4	3.5	0	27.3	3.4	3.5	0	27.3	3.4	3.5
Denuded forest land-1 (%)	0	10.5	0.6	1.1	0	9.0	0.6	1.2	0	16.7	0.9	1.6
Denuded forest land-2 (%)	0	74.5	4.2	7.7	0	67.3	3.6	7.4	0	67.3	4.0	7.4
Financial independence rate	8.5	95.0	32.5	18.1	6.9	92.6	30.2	17.5	8.6	82.9	28.2	16.5
Volume of retarding basin	0	4238000	93545	357143	0	4238000	90711	357060	0	4238000	100145	375803
Sewerage system supply rate	8.3	100.0	68.5	27.9	0	100.0	66.3	31.0	1.4	100.0	76.3	24.4
Old buildings (%)	0.0001	0.438	0.134	0.106	0.004	0.442	0.146	0.106	0.002	0.466	0.160	0.116
Empty houses (%)	0.011	0.210	0.062	0.037	0.016	0.297	0.080	0.045	0.014	0.292	0.082	0.048
Disabled (%)	9.0	42.0	17.7	4.7	2.4	10.9	5.8	2.1	2.5	11.6	6.5	2.2

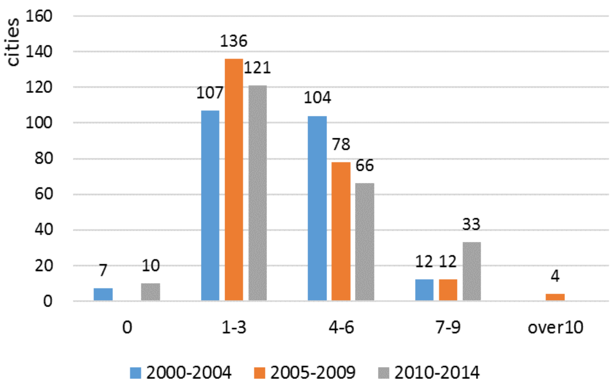
* Property damage: per 1,000 person (unit: 1,000 won)

a. Urbanization variable

To estimate the effect of urbanization on flood property damage, we measured two indicators, *the degree of an area's urbanization* and *population density in an urbanized area*. *The degree of an area's urbanization* was measured by dividing the urbanized area by total area based on the data from the National Statistical Office. An increase in urbanized area is associated with increasing impervious surfaces and population. While the *population density in an urbanized area* is measured by dividing the total number of people living in an urbanized area by its total area of land. This can be an indicator of urban size along with the degree of an area's urbanization. There is an agreement that the more people reside in the area, the more probability there is of damages being generated during a flood event (Zahran, 2008).

b. Hazard related variables

We measured three hazard related variables to estimate the force of a flood. The first variable of flood force is *flood frequency*. This means how many times flood damage occurred from 2000 to 2014 in each region. We got this data by counting the number of flood events that appeared in the yearbooks of disaster. Figure 3 shows the number of cities in which the flood frequency is within each criteria. The flood frequency in cities were mostly recorded as being over 1 and under 6 during each period. In all periods, the number of cities decrease as the flood frequency increases. Figure 4 shows the average flood frequency in urban and rural areas over 15 years. This result shows that floods occurred more frequently in rural areas.



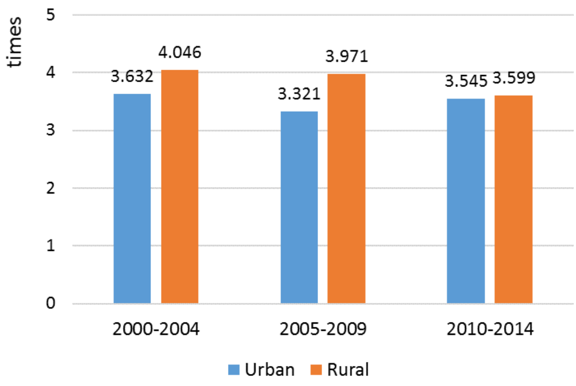


Figure 3. Flood frequency and the number of cities Figure 4. An average number of flood frequency

The other two variables, *Precipitation-1* (average of daily maximum precipitation during flood period) and *Precipitation-2* (average of total accumulated precipitation during flood the occurrence period), are measured by using weather observation data. The Korea Meteorological Administration furnish various weather observation data at hourly time intervals including precipitation, temperature, wind direction and velocity and so on. The precipitation data set used in this study, is based on the observation date measured in 93 ground-based meteorological observation stations over fifteen years (2000-2014). To process the hazard related variables, this study follows 3 steps.

First, the rainfall intensity is measured at 1minute time intervals, but normally provided at 1hour time intervals. We convert 1hour time interval data into 1day time intervals in order to unite all data units. Second, the number of meteorological observation stations varies across the cities. In addition, in some locations, there were missing data due to the elimination and re-establishment of ground-based meteorological observation stations. In this study, these missing data were excluded. Meanwhile we used an interpolation method to predict values for 230 regions from the 93 stations. The x, y coordinate of each region was extracted from the location of city hall on the map. Third, we created weather related variables by averaging and summing consecutive observations in a series. *Precipitation-1* variable was measured by extracting daily maximum precipitation during each floods. And an accumulated rainfall data measured as the sum of precipitation during flood periods.

c. Topographical variables

Four predictors were used to estimate the effect of topographical and geographical condition on floods: *River area-1* (density of main stream area), *River area-2* (density of branch and small river area), *Floodplain area*, and *Steep slope-land.* We measured two river-related variables by using GIS and the National Hydrography Dataset. We calculated the ratio of the main stream area and a sum of branch and small-river area to an area of the region. In general, an area with high stream density will be more likely to be exposed to flood events (Horton, 1932; Brody, 2007; Kang, 2011; Shim et al, 2012). But the impact of main stream and branches will be different depending on their width and height, constructed flood control infrastructure, rate of preventive maintenance, and refurbishment. We also used a GIS to measure *the area of floodplain* and *the area of steep slope-land*. In the case of floodplain, we extracted a 0-2° slope area within 200 meters from the river line. The slope value was calculated by using a soil data and digital elevation model (DEM) file. DEM data was classified at a 30meter spatial resolution. The low-lying and low-slope areas in floodplains are more vulnerable to the impact of excess run-off through river networks. Lastly we measured *steep slope-land variable* to estimate the effect of soil erosion and landslide. We extracted a 60-100° slope area from the soil data and DEM file, and then calculated *the rate of steep slope-land* to area of the region.

d. Land use variables

We measured six land use variables expected to affect the degree of flood damage: *Impervious area in floodplain area, Farmland area in floodplain area, Impervious area in Steep slope-land, Farmland area in Steep slope-land, Denuded forest land-1* (unwooded), and *Denuded forest land-2* (covered with road, stream, rock and others). We calculated the impervious area and farmland in a floodplain or steep slope-land by using a land cover GIS layer derived from the classification of Korean Multipurpose Satellite-2 (Arirang-2) imagery published at 5meter spatial resolution by the department of the Environment in

2007. Those two land cover features are based on criteria offered on the governmental public web site (EGIS). Impervious area contains several types of covered area such as residential, industrial, commercial, cultural, pavement/road, and others. Farmland is calculated as a summation of plow-land, orchard and others. The agricultural lands to floodplain and steep slope-land can diminish the hydrological system, resulting in increased flood severity (Carter, 1961; Tourbier and Westmacott, 1981; Zharan, 2008). Meanwhile, there is a lack of time-sensitive land cover data due to the data availability. The constructed nation-wide land cover map was published only in 2007. Thus we selected the 2007 land cover data which is in the middle of the study period.

To measure other two variables, *Denuded forest land-1 and Denuded forest land-2*, we analyzed statistical forest data from the National Forestry Administration. *Denuded forest land-1* was measured as a summation of unwooded and waste land, except the area covered with road, rocks, facilities, and water. Areas covered with road, rock, facilities and water were categorized as *Denuded forest land-2*. According to the report published by the Korea forest research institute, those denuded forest land has higher tendency to generate land slide (1.6 times) and soil erosion (236.3 times per hectare) compared with tree-grown area.

e. Capacity related variables

This group contains three factors reflecting regional capability to mitigate and respond to flood damage - *Financial independence rate, Volume of retarding basin, and Sewerage system supply rate.* We used the KOSIS database to find regional data opening to the public. Firstly, *Financial independence rate* means the ratio of local independent revenue to total revenue. It is used to describe the city as having sufficient wealth to operate their administrative tasks. The researchers assumed that financially independent cities can be flexible in responding to disasters by investing in both infrastructural facilities and policies, which can contribute to reduce damages from disaster (Kang, 2011; Park et al, 2010). Secondly*, Volume of retarding basin* is an inner water drainage facility which plays an important function in managing inner water in the local area. The retarding basins are usually located in low-lying areas of land in order to temporarily store water during flood events. To collect this variable, we used the yearbooks of sewerage arrangements provided by the department of Environment in Korea. *Volume of retarding basin* variable is measured as a total value rather than a relative rate in order to compare absolutely those factors. Lastly, *Sewerage system supply rate* is a percentage of population within the sewerage system. Although the major role of sewerage system is to transport sewage from residential and commercial buildings through underground pipes, it is often considered as a water managing facility because it reduces the water table in an area (Shin, 2011; Choi, 2013). We expected capacity related variables to be negatively associated with flood property damage.

f. Socioeconomic variables

We measured four socioeconomic predictors shown to affect the degree of flood damage: *the ratio of old buildings, the ratio of empty houses*, and *the ratio of disabled people* to the total population. Firstly, we measured *old buildings* by dividing the sum of buildings over 30 years old by the total residential buildings in a region. We used the data from the Korea Statistical and Geographical Information Service online search engine. It is reasonable to consider that old buildings are more vulnerable to flood events because deteriorated buildings are more likely to have cracks and leakages. The second socioeconomic variable is *Empty houses*. We used total empty houses data inventoried in the KOSIS databases. This was also measured by dividing the number of empty houses by the total residential buildings in region. The *Empty houses*, in common with the *old building* variable, can be easily damaged from flooding because these are usually not managed well. Lastly, we measured *the ratio of disabled people* to the total population based on the data inventoried in the KOSIS databases. Cutter (1996) suggested that the hazard potential is related with two factors; geographic context and Social fabric, and those two factors interact to produce the place vulnerability. From this we can examine whether socially vulnerable populations are susceptible to flood events in Korea.

3.3 Analytical Methods

We analyze the data in five phases as follows:

First, we reported descriptive statistics regarding reported flood occurrences, victims and property damage from 2000 to2014.

Second, before the flood risk assessment was started, all dependent variables were checked for normal distribution. The sample size will be reduced to less than 100 after being divided into urban and rural groups. So, a log equation was applied to all dependent factors which do not belong to normal distribution after checking the Kruskal-Wallis test and histogram using SPSS 21.0. All variables are in normal distribution after log transition.

Third, we identified the presence of autocorrelation and multi-collinearity among independent variables by checking the Durbin-Watson statistics and the variance inflation factor (VIF) in estimated models. All VIF scores are in the acceptable range under 10.

Fourth, we examined the relationship between flood property losses and parameters affecting flood damage through the Pearson's correlation analysis during three time periods.

Last, we performed a multiple linear regression analysis to estimate the effect of urbanization and other independent variables on reported flood property damage in Korea during three study periods, 2000-2004, 2005-2009, and 2000-2014.

Ⅳ. Results

4.1 Descriptive statistics

The first phase of our research is descriptive statistics. Table 3 ranks the top 50 regions on total property loss for the study period 2000-2014. Overall, total property damage is recorded at over 5,982 billion won. And 189,568 persons were affected from floods including housing loss, death, injured and missing. The average number of flood occurrences over 15 years was 10.46 per city and the property damage records were over 2.4 billion won per flood event. The highest property damage was recorded at over 647 billion won in Pyeongchang-gun in Gangwon province. Interestingly, a total of eight cities belong to Gangwon province are in the top ten. In regard to this matter, the majority of property loss occurred on July 2006 and almost all the property damages of Kangwon and Kyunggi province were reported during this period. In general, the pattern of the amount of property damage does not follow the victims and flood frequency pattern. In addition, both property losses and victims are somewhat concentrated in several areas. For example, Yangyang-gun, which located in Kangwon province, reported 118 billion won in damage but experienced a comparatively low 8 flood events during the study period. And Ulju-gun which is contained in Ulsan metropolitan city, records relatively low 1 billion property losses and 10 flood events, but total 1,071 people were suffered during 15 years. This result indicates that there are other parameters affecting the degree of flood damage other than flood frequency.

We reorganized all cities into 16 metropolitan area groups, and report total flood property damages during three study periods in Figure 5. In the early half of the 2000s, property damage occurred in various regions, whereas, in the latter half of the 2000s, property damage is focused on Gangwon province. And in recent periods, Kyunggi province experienced the most serious property damages. The majority of damages occurred on three time periods in early August 2002, mid-July 2006, and late July 2011. In August 2002, rains fell for eight days in the country, peaking at 320 mm in a day in Yangpyeong-gun, Kangwon province. The heaviest of the precipitation fell in Hongcheon-gun, where a station reported 74 mm in one hour. Most of the damages occurred due to the lack of drainage systems and the breaking of embankments. At least 2,933 houses were flooded, and 8,107 peoples were damaged. Flooding in July 2006 caused extensive damage and loss of life. About 63 people are either dead or missing and over 9,340 residents become homeless. The intense rain triggered a series of flash floods and landslides in Kangwon and Kyungnam province. The heaviest of the accumulated precipitation fell in Hongcheon-gun, where a station reported 563 mm in a day. While, in late July 2011, floods occurred primarily around the national capital Seoul and nearby Kyunggi regions, as well as Kyungnam and Kangwon province. At least 62 are died and 9 people are missing. In particular, a landslide in Umyeon-dong killed 18 residents in an apartment. Due to the heaviest precipitation in the Seoul region, highways and tracks of the Seoul Metropolitan Subway were inundated, while bridges over the Han River were closed off.

Table 3. Top 50 regions in terms of flood property damage, 2000-2014

Rank	Province	Region	Total property damage (thousands of 2010 KRW)	Victims	Number of floods
1	Gangwon	Pyeongchang-gun	647,578,099	1,322	16
2	Gangwon	Inje-gun	557,431,624	808	15
3	Kyungnam	Gimhae-si	246,631,846	3,810	7
4	Gangwon	Hongcheon-gun	150,460,029	156	12
5	Gangwon	Jeongseon-gun	142,453,985	148	11
6	Gangwon	Hoengseong-gun	118,697,881	174	11
7	Gangwon	Yangyang-gun	118,015,250	36	8
8	Jeonbuk	Jinan-gun	97,711,689	208	14
9	Gangwon	Yeongwol-gun	95,208,780	194	9
10	Gangwon	Chuncheon-si	90,415,945	719	16
11	Jeonbuk	Jangsu-gun	88,861,936	285	13
12	Kyunggi	Pocheon-si	88,824,245	958	15
13	Kyunggi	Gwangju-si	82,918,977	6,401	9
14	Chungbuk	Danyang-gun	82,200,282	155	10
15	Jeonbuk	Muju-gun	80,037,251	74	13
16	Chungbuk	Jecheon-si	76,917,133	195	15
17	Kyunggi	Icheon-si	72,340,327	1,013	18
18	Gangwon	Yanggu-gun	68,820,591	73	15
19	Kyunggi	Yeoju-gun	67,560,152	657	9
20	Busan	Gijang-gun	67,118,162	1,559	8
21	Kyunggi	Yeoncheon-gun	66,306,245	868	22
22	Kyungbuk	Bonghwa-gun	58,512,136	552	9
23	Kyungnam	Hadong-gun	57,901,651	270	9
24	Kyunggi	Gapyeong-gun	56,726,847	454	19
25	Kyunggi	Yongin-si	56,181,611	3,344	9
26	Kyunggi	Yangpyeong-gun	55,735,871	378	15
27	Kyungnam	Changwon-si	54,174,612	1,149	25
28	Jeonbuk	Wanju-gun	54,163,238	133	14
29	Kyungnam	Miryang-si	50,759,599	770	11
30	Gangwon	Wonju-si	47,898,720	231	16
31	Chungbuk	Jincheon-gun	47,473,038	588	14
32	Chungbuk	Chungju-si	47,232,627	32	16
33	Kyungbuk	Andong-si	47,195,175	293	17
34	Kyungnam	Goseong-gun	45,677,089	52	9
35	Gangwon	Gangneung-si	45,617,751	56	9
36	Kyungnam	Jinju-si	45,311,741	148	15
37	Kyunggi	Anseong-si	44,543,771	783	15
38	Kyungnam	Hapcheon-gun	42,663,043	81	11
39	Chungnam	Geumsan-gun	41,940,694	141	18
40	Kyunggi	Yangju-si	41,815,599	834	17
41	Kyunggi	Paju-si	41,693,074	2,166	19
42	Gangwon	Hwacheon-gun	41,069,934	59	12
43	Jeonbuk	Imsil-gun	40,120,958	467	13
44	Kyunggi	Namyangju-si	39,582,785	1,579	10
45	Kyungnam	Sancheong-gun	39,155,733	45	9
46	Kyungnam	Haman-gun	38,250,397	91	8
47	Kyungnam	Yangsan-si	35,956,081	663	11
48	Jeonbuk	Namwon-si	35,834,815	83	19
49	Ulsan	Ulju-gun	34,536,381	1,071	10
50	Kyungnam	Uiryeong-gun	33,195,224	55	10
Total			5,982,881,996	189,568	2,406

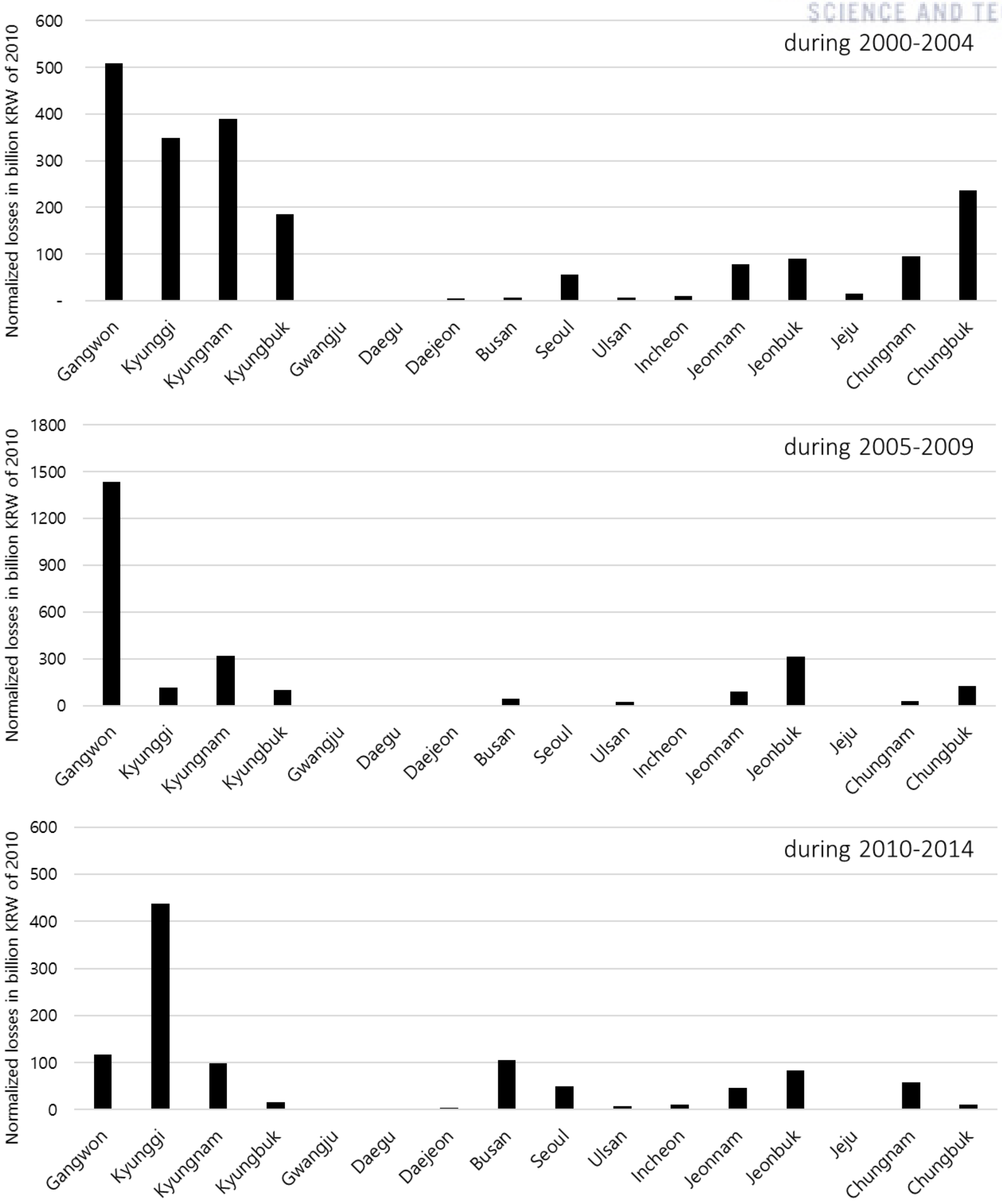


Figure 3. Reported flood property losses of 16 metropolitan areas during 2000-2004 (top), 2005-2009 (middle), and 2010-2014 (bottom)

4.2 The results of correlation analysis

In the second phase of analysis, we performed the Pearson's correlation analysis. Table 4 shows a result of the correlation between property damage and selected predictors in each of the three periods. Firstly, urbanization parameters – urbanization and urban population density –are strongly correlated with log transformed property damage in all periods. Second, among hazard related variables, flood frequency is positively significant with property damage in all periods, but the coefficient reduced in recent years. Meanwhile, precipitation variables are negatively correlated with property damage and are not significant between 2010 and 2014. This result looks somewhat different to regional research. Third, *river area-1* (main stream) and river area-2 (branches and small rivers) are statistically significant in all periods but in different directions. According to the report published by the National Assembly Budget Office in 2012, maintenance of the levee system has been operated better in main streams (79.4%) than in branches (57.6%) and small rivers (42.0%) (Kim, 2012). When we consider this, the correlation result can be interpreted as reflecting overall conditions of river areas including infrastructures. Floodplain area is negatively associated with flood property damage, contrary to our expectations, and the steep slope-land is not significant in all periods. This result seems to reflect the effects of our flood mitigation policies, because our flood mitigation measures are mostly focused on the prevention of riverine floods

Table 4. The correlation result between property damage and independent variables

	log damage (00-04)	log damage (05-09)	log damage (10-14)
Urbanization	**-.677****	**-.697****	**-.467****
Urban population density	**-.446****	**-.574****	**-.295****
Flood frequency	**.446****	**.402****	**.242****
Precipitation-1	**-.186****	**-.289****	-.006
Precipitation-2	**-.179****	**-.262****	-.022
River area-1	**-.265****	**-.345****	**-.189****
River area-2	**.513****	**.617****	**.314****
Floodplain area	**-.226****	**-.246****	-.031
Steep slope-land	.074	.053	.091
002 Impervious area	**-.424****	**-.504****	**-.318****
002 Farmland	**.360****	**.355****	**.216****
610 Impervious area	**-.296****	**-.210****	-.112
610 Farmland	**.162***	**.156***	.050
Denuded forest land-1	.038	.064	.000
Denuded forest land-2	**-.226****	**-.268****	**-.137***
Financial independence rate	**-.428****	**-.539****	**-.189****
Volume of retarding basin	**-.174****	**-.272****	-0.055
Sewerage system supply rate	**-.593****	**-.570****	**-.352****
Old buildings	**.500****	**.530****	**.298****
Empty houses	**.578****	**.645****	**.469****
Disabled	**-.200****	**.617****	**.394****

** $p \le 0.01$ * $0.01<p<0.05$

for a long time. Fourth, regarding land use variables, all variables have a significance except *denuded forest land-1* (unwooded) from 2000-2009. Generally, impervious variables negatively predict the likelihood of flood damage, though it positively predicts by farmland variables. This result seems to reflect the different land use characteristics between urban and rural. If less urbanized regions are damaged more, variables related to rural characteristics would be significant in the model. Meanwhile, during the 2010-2014 period, separated land use variables measuring from the steep slope-land variable and *denuded forest land-1* are not statistically significant. Fifth, all capacity related variables – financial independence rate, volume of retarding basin, and sewerage system supply rate – are negatively correlated with property damage. Financial independence rate and sewerage system supply rate show a strong correlation, but the coefficient also decreased during the last five years. Lastly, old buildings and empty houses are strongly significant with positive direction in all periods. On the other hand, the disabled variable shows a negative correlation with property damage during the 2000-2004 period.

4.3 Flood risk assessment using multiple regression analysis

Flood risk assessment during 2000-2004

In the third phase of research, we examined the influence of urbanization, hazard related, topographical, capacity related and socioeconomic variables using multiple linear regression. We added the following set of variables to urbanization variables to identify their effects both individually and entirely: natural environmental variable group (hazard related variables and topographical variables), capacity related variable group, and socioeconomic variable group.

Table 5 reports the result of regression predicting flood property damages during 2000-2004. As a whole, urbanization variables and natural environment variables explain 67.9% (adjusted 66.5%) of the variance in flood risk model in Korea. The degree of an area’s urbanization has the strongest relation to property damages ($b=-.577$, $p<0.01$). Flood frequency ($p=-.306$, $p<0.01$) and two precipitation variables are also strongly associated with property damages in a positive direction. Among topographical variables, only steep slope-land variable positively predicts the likelihood of flood property damages.

When we add the three capacity related variables in Model 2, the effect of urbanized area is diminished appreciably. And precipitation-2 (total accumulated precipitation during flood occurrence period) becomes not significant anymore. In contrast, sewerage system supply rate is 0.243 times more likely to decrease property damage.

Finally, the fully specified model (Model 3) explains 71% of variance in flood property damage. The most significant predictors are still effective in this model, but the effect of sewerage system supply rate is notably reduced ($b=-.160$, $p<0.1$). Meanwhile, the empty houses variable is statistically

Table 5. Multi-linear regression models predicting flood property damages (2000-2004)

	Model 1		Model 2		Model 3	
	β	Beta	β	Beta	β	Beta
Constant	-.719		.462		-.630	
Urbanization variables						
Urbanized area	-.035 ***	-.577	-.023 ***	-.374	-.020 ***	-.322
Urban population density	-49.544 *	-.117	-49.654 *	-.116	-53.78 **	-.126
Hazard related variables						
Flood frequency	.458 ***	.306	.511 ***	.339	.521 ***	.345
Precipitation-1	.014 ***	.246	.016 ***	.281	.015 ***	.260
Precipitation-2	.004 **	.133	.002	.058	.003	.086
Topographical variables						
River area-1	-2.556	-.032	.043	.001	-1.262	-.016
River area-2	-2.782	-.013	-11.93	-.054	-8.152	-.037
Floodplain area	-.002	-.005	-.001	-.001	.004	.010
Steep slope-land	.034 ***	.250	.035 ***	.257	.031 ***	.228
Capacity related variables						
Financial independence rate			.003	.024	.001	.006
Volume of retarding basin			-3.501	-.051	-3.564	-.052
Sewerage system supply rate			-.022 ***	-.243	-0.015 *	-.160
Socioeconomic variables						
Old buildings					-.466	-.020
Empty houses					12.41 ***	.174
Disabled					-.177	-.056
N	215		216		216	
R^2	.679		.692		.710	
Adjusted R^2	.665		.674		.688	
Durbin-Watson	1.782		1.703		1.741	
Probability > F	.000		.000		.000	

*** p≤ 0.01, ** p≤0.05, * p≤0.1

significant (b=.174, p<0.01). Old buildings and the disabled variable have negative directions. With the models predicting flood property damages, we analyzed urban and rural property damages to examine whether geographic localities characterized by the degree of an area's urbanization have a different pattern on flood risk. Table 6 is the result of a multi regression model comparing urban and rural during the 2000-2004 period. A total of 63 observations are contained in the urban model, and it increases to 111 in the rural model.

Firstly, hazard related variables, especially flood frequency and accumulated precipitation, are positively significant in both groups, as expected. Flood frequency increases the odds of flood property damages by 0.488 percent in urban areas, where p<0.01. On the other hand, topographical variables are statistically significant only in the rural group, facing in different directions. The percentage of the floodplain area significantly decreases the probability of flood damage (b=-.284, p<0.01), and the percentage of steep slope-land area increases the likelihood of flood damage. Steep slope-land is .272 times more likely to cause flood damages where p<0.01. The results of land use variables derived from floodplain areas are quite different in urban and rural areas. In urban areas, an increase of the development of floodplain areas to impervious areas (b=.300, p<0.05) and farmland (b=.211, p<0.1) positively effects property damage. But in rural areas, the more impervious area that increases in floodplains, the less property losses occur (b=-.305, p<0.01). In contrast, land use variables derived from steep slope-land shows a similar pattern in urban and rural areas. Impervious areas in steep slope-land significantly decreases the odds of property damages and farmland in steep slope-land is not statistically significant in either group. Meanwhile, in the result of capacity related variables, the financial independence rate positively predicts the probability of flood damage in urban (b=.185, p<0.1) and rural areas (b=.258, p<0.05) during 2000-2004. The volume of retarding basin is not statistically associated with property loss in both groups, and sewerage system supply rate is negatively significant only in the urban group. Regarding socioeconomic variables, a density of empty houses in rural and a density of disabled people in urban areas are an increasing factor in the regional flood risk model. But the disabled variable negatively affects property damage in the rural group, unlike the result of the urban group.

Flood risk assessment during 2005-2009

Table 7 reports the result of multi-linear regression predicting flood property damages during 2005-2009. As shown in Model 1, urbanization variables and natural environment variables explain 66.1% (adjusted 64.6%) of the variance in the flood risk model in Korea. When we add the capacity related variables, the model explanation is somewhat increased to 68.2% (adjusted 66.3%). However, the Durbin-Watson of those two models are not in an acceptable range, from 1.5 to 2.5. So we need to recognize there is a negative autocorrelation in the residuals in Model 1 and Model 2.

Table 6. Multi regression models predicting log transformed property damages occurred by flooding in Urban and Rural (2000-2004)

	Urban			Rural		
	β	S.E.	Beta	β	S.E.	Beta
Constant	-6.621 **	(2.8438)		1.439	(.8804)	
Hazard related variables						
Flood frequency	.750 ***	(.1411)	.488	.289 ***	(.0759)	.294
Precipitation-1	.013 **	(.0061)	.304			
Precipitation-2	.006 **	(.0030)	.269	.008 ***	(.0022)	.291
Topographical variables						
Floodplain area				-.102 ***	(.0059)	-.284
Steep slope-land				.022 ***	(.0290)	.272
Land use variables						
002 Impervious area	.022 **	(.0079)	.300	-.076 ***	(.0194)	-.305
002 Farmland	.025 *	(.0133)	.211			
610 Impervious area	-.030 **	(.0124)	-.214	-.678 ***	(.1645)	-.327
610 Farmland						
Capacity related variables						
Financial independence rate	.022 *	(.0121)	.185	.037 **	(.0127)	.258
Volume of retarding basin						
Sewerage system supply rate	-.040 **	(.0194)	-.194			
Socioeconomic variables						
Old buildings						
Empty houses				8.005 **	(3.4971)	.155
Disabled	1.491 **	(.6817)	.240	-.251 **	(.1000)	-.163
N	63			111		
R^2	.608			.616		
Adjusted R^2	.541			.582		
Durbin-Watson	1.836			1.877		
Probability > F	.000			.000		

*** p≤ 0.01, ** p≤0.05, * p≤0.1

We exclude a detected outlier in Model 1, so the number of observations is lower than in other models. Urbanization variables are still strongly associated with flood property damages. Although the effect is quite reduced compared to prior five-years model 2000-2004, the percentage of urbanized area is the most critical variable in Model 1 (b=-.411, p<0.01). And the flood frequency and steep slope-land variable still positively predicts the likelihood of flood property damage. However, unlike the prior total flood risk model (2000-2004), precipitation variables are statistically insignificant.

When we add capacity related variables (Model 2), the effect of urbanized area is notably decreased (b=-.283, p<0.01). And sewerage system supply rate shows a negative significance.

Model 3 explains 69.6% of variance in flood property damage and has an acceptable Durban-Watson value. In this model, all significant variables in Model 1 and Model 2 maintain their characteristics except for the sewerage system supply rate variable. After adding the socioeconomic variables, the sewerage system supply rate is not associated with flood property damages anymore. In this model, the odds of property damage rise with the increase of empty houses (b=.128, p<0.05).

As a whole, significant variables and their directions mostly follow similar patterns to the prior total model (2000-2004). However, there are two differences regarding significance and directions. First, two precipitation variables are not statistically significant in flood risk model during 2005-2009 and even precipitation-2 variable (accumulated precipitation) has a negative direction. It means that meteorological parameters are not critical for predicting flood property damage during this study period. Second, capacity related variables are not associated with flood property damages in the final model. Only the sewage system supply rate significantly predicts flood damage in Model 2, but it disappears when we add the socioeconomic variables.

Table 8 reports the result of regional regression models during 2005-2009. In urban group, the number of observations are reduced from 74 to 58 due to lack of data, while there is no missing data in the rural group. In the urban group, five significant variables explain 48.7% (adjusted 43.7%) of the variance in the flood property damage model. Also, in the rural group, five variables are significant and their explanation is 52.5% (adjusted 50.2%).

Like the preceding result of regional regression model, flood frequency, impervious area and farmland in floodplain area are statistically significant in the urban group. And impervious area, farmland, empty houses, and disabled variable significantly predict flood property damage in the rural group. However, a direction of impervious area in steep slope-land is changed in urban group during 2005-2009. This means that regions which have a higher percentage of impervious area in steep slope-land are more likely to experience flood property damages. A direction of disabled variable is also changed in the rural group during 2005-2010. This variable becomes a positive parameter in predicting flood property damages in rural areas.

Table 7. Multi-linear regression models predicting flood property damages (2005-2009)

	Model 1		Model 2		Model 3	
	β	Beta	β	Beta	β	Beta
Constant	2.912 ***		3.732 ***		.761	
Urbanization variables						
Urbanized area	-.028 ***	-.411	-.020 ***	-.283	-.013 **	-.193
Urban population density	-72.800 **	-.135	-82.047 **	-.152	-80.170 **	-.148
Hazard related variables						
Flood frequency	.208 ***	.156	.220 ***	.163	.201 ***	.149
Precipitation-1	.007	.141	.009	.175	.009	.168
Precipitation-2	-.004	-.161	-.004	-.151	-.004	-.153
Topographical variables						
River area-1	4.119	.044	5.452	.057	6.735	.070
River area-2	-13.602	-.058	-22.294	-.093	-16.440	-.068
Floodplain area	-.038	-.079	-.033	-.068	-.041	-.083
Steep slope-land	.054 ***	.362	.050 ***	.331	.047 ***	.308
Capacity related variables						
Financial independence rate			-.012	-.075	.003	.018
Volume of retarding basin			-6.600	-.050	-7.978	-.060
Sewerage system supply rate			-.013 **	-.140	-.006	-.064
Socioeconomic variables						
Old buildings					.570	.022
Empty houses					7.972 **	.128
Disabled					.198	.146
N	213		214		214	
R^2	.661		.682		.696	
Adjusted R^2	.646		.663		.673	
Durbin-Watson	1.465		1.442		1.505	
Probability > F	.000		.000		.000	

*** p≤ 0.01, ** p≤0.05, * p≤0.1

Table 8. Multi regression models predicting log transformed property damages occurred by flooding (2005-2009)

	Urban			Rural		
	β	S.E.	Beta	β	S.E.	Beta
Constant	-3.552 ***	(.6018)		-2.059 *	(1.0465)	
Hazard related variables						
Flood frequency	.575 **	(.1783)	.349			
Precipitation-1				.018 ***	(.0053)	.269
Precipitation-2						
Topographical variables						
Floodplain area				-.089 **	(.0379)	-.188
Steep slope-land	.095 ***	(.0197)	.499	.039 ***	(.0085)	.369
Land use variables						
002 Impervious area						
002 Farmland	.027 *	(.0139)	.214			
610 Impervious area	.030 *	(.0170)	.181			
610 Farmland						
Capacity related variables						
Financial independence rate						
Volume of retarding basin						
Sewerage system supply rate						
Socioeconomic variables						
Old buildings	9.621 **	(4.2892)	.234			
Empty houses				10.98 **	(4.0938)	.213
Disabled				.393 ***	(.1093)	.283
N	58			107		
R^2	.487			.525		
Adjusted R^2	.437			.502		
Durbin-Watson	1.522			1.564		
Probability > F	.000			.000		

*** p≤ 0.01, ** p≤0.05, * p≤0.1

Generally, the effects of hazard related variables, land use variables and capacity related variables are reduced during 2005-2009 compared to the results of 2000-2004. In particular, there is no significant variable among capacity related variables in both urban and rural areas. This result reflects a result of multi-linear regression model presented in Table 7.

Flood risk assessment during 2010-2014

We conducted a Multi-linear regression to indicate which factors significantly affect flood property damage during 2010-2014 (see Table 9). In Model 1, urbanized area is strongly significant, but urban population density is not significant. In terms of hazard related variables, our results show that flood frequency and precipitation-1 positively predict odds of flood property damages. Precipitation-1 (daily maximum precipitation) is more than twice as effective as precipitation-2 (accumulated precipitation). In this model, precipitation-2 has a negative direction like the result of model predicting total flood property damages during 2005-2009 ($b=-.220$, $p<0.05$). And among topographical variables, only river area-1 (main stream) predicts positively the likelihood of flood property damages ($b=.187$, $p<0.05$).

In Model 2, the effect of flood frequency is stronger than Model 1. And the steep slope-land variable becomes a significant parameter, as does *river area-1* among topographical variables. On the other hand, all capacity related variables are not statistically significant in Model 2. When we add socioeconomic variables, the explanation of variance is somewhat increased to 48.4% (adjusted 44.6%). Among components, hazard related variables and socioeconomic variables are strongly associated with flood property damage in the full model. Meanwhile, capacity related variables are statistically insignificant during 2010-2014.

These results are quite distinct in the regional model (see Table 10). Flood frequency and precipitation variables are the most powerful in urban and rural areas. But *precipitation-2* significantly decreases the likelihood of property losses only in the urban group ($b=-.632$, $p<0.05$). In the urban group, as the percentage of steep slope-land area increases, the likelihood of property losses is decreased by flood events. In terms of land use variables, farmland in the floodplain area is 0.183 times more likely to decrease flood property damages in urban areas, and farmland in steep slope-land areas is 0.259 times more likely to decrease property losses in rural areas. Also, regarding socioeconomic variables, the disabled variable shows a different direction between urban and rural areas. It is positively associated with flood property damage in urban areas, but it is negatively significant in rural areas. The empty houses variable is one of the significant variables positively associated with flood property damage in rural group. As with the total model, capacity related variables are not significant in the regional model during 2010-2014.

Table 9. Multi-linear regression models predicting flood property damages (2010-2014)

	Model 1		Model 2		Model 3	
	β	Beta	β	Beta	β	Beta
Constant	.360		1.170		-3.505 **	
Urbanization variables						
Urbanized area	-.034 ***	-.574	-.028 ***	-.466	-.019 **	-.311
Urban population density	12.734	.031	9.780	.024	32.218	.078
Hazard related variables						
Flood frequency	.280 ***	.370	.304 ***	.402	.279 ***	.369
Precipitation-1	.019 ***	.464	.020 ***	.479	.023 ***	.564
Precipitation-2	-.005 **	-.220	-.005 **	-.226	-.008 ***	-.347
Topographical variables						
River area-1	15.077 **	.187	14.487 **	.180	13.173 **	.163
River area-2	-.315	-.001	-7.046	-.033	-11.031	-.052
Floodplain area	-.051	-.119	-.045	-.104	-.043	-.101
Steep slope-land	.025	.181	.026 **	.189	.018 *	.129
Capacity related variables						
Financial independence rate			-.008	-.056	.009	.064
Volume of retarding basin			2.033	.031	-2.921	-.004
Sewerage system supply rate			-.012	-.119	-.001	-.008
Socioeconomic variables						
Old buildings					-5.511 **	-.256
Empty houses					13.994 ***	.275
Disabled					.491 **	.443
N	220		220		220	
R^2	.424		.432		.484	
Adjusted R^2	.399		.399		.446	
Durbin-Watson	1.628		1.591		1.702	
Probability > F	.000		.000		.000	

*** p≤ 0.01, ** p≤0.05, * p≤0.1

Table 10. Multi regression models predicting log transformed property damages occurred by flooding (2010-2014)

	Urban			Rural		
	β	S.E.	Beta	β	S.E.	Beta
Constant	1.663	(1.7214)		-3.946 ***	(1.1847)	
Hazard related variables						
Flood frequency	.192 **	(.0691)	.313	.390 ***	(.0662)	.464
Precipitation-1	.021 **	(.0068)	.639	.022 ***	(.0037)	.460
Precipitation-2	-.011 **	(.0034)	-.632			
Topographical variables						
Floodplain area						
Steep slope-land	.047 **	(.0207)	.237			
Land use variables						
002 Impervious area						
002 Farmland	-.023 *	(.0135)	-.183			
610 Impervious area						
610 Farmland				-.183 ***	(.0532)	-.259
Capacity related variables						
Financial independence rate						
Volume of retarding basin						
Sewerage system supply rate						
Socioeconomic variables						
Old buildings						
Empty houses				13.82 ***	(3.9391)	.267
Disabled	-.592 **	(.3299)	-.191	.219 **	(.1100)	.158
N	71			102		
R^2	.348			.468		
Adjusted R^2	.287			.440		
Durbin-Watson	1.798			1.724		
Probability > F	.000			.000		

*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.1$

Ⅴ. Discussion

There are several important implications for decision makers regarding the time-trend analysis and urban-rural analysis. First, urbanization is one of the critical factors in influencing the degree of flood property damage in Korea in the 15 year periods, especially cities with a lower percent of urbanized area, which are more likely to suffer property loss from flood events. In the literature review above, we examine that there is an argument about urbanization whether increased income acts as an aggravating factor for flood damage or not. In short, there are two main viewpoints that the rise of wealth associated with urbanization causes an increase of property loss in disaster situations, and vice versa, it may contribute to reduce flood property damage by attracting investment on both flood defences and disaster mitigation policies. Based on the literatures, our results support the conclusion that urbanized cities have invested on flood mitigation measures using the increased wealth, and it leads to decrease of flood property damages during 15 years. At the same time, it means that our flood mitigation measures have focused on the riverine flood and internal inundation which are usually occurred in urban area, so rural area become relatively vulnerable to flood events (Park, 2011; Hong and Hwang, 2006).

The principal reason for identifying relationship between urbanization and flood damages is to prevent overestimate of flood vulnerability in urban area. For example, social, economic and built environmental variables such as population density, wealth, housing density, public facility, impervious area, and development area are commonly used to risk assessment at national level (Park et al, 2010; Jung et al, 2014; Lee et al, 2010). But those variables are linked closely with urbanization factor, so they show a high value in urban area. It means that if the relationship among variables are not carefully considered, so capacity related and topographical factors are overlooked in risk assessment model, then flood vulnerability of rural area can be underestimated.

Second, the result of the relationship between two precipitation variables (daily maximum precipitation and total accumulated precipitation during the flood occurrence period) and flood property damage, indicate that the total amount of precipitation is not as important as the concentration of rainfall, in determining the extent of property damage in Korea. That is, heavy downpours that occur in a short time can generate much bigger damages than precipitation which accumulates over a longer time. Our study estimates that an influence of daily maximum rainfall on the likelihood of flood property damage increased to nearly 2 times in the last five years compared with 2000-2004. Also, frequency is one of the most important factors to predict flood property damage in our model. The effect of frequency is somewhat decreased during 2005-2009, but still has positive relation.

Of course, it is too early to make a conclusion base on our results that the damage from extreme rainfall events has increased during 15 years, but this finding has several implications for decision makers when we consider that many studies indicate the intensity and frequency of extreme weather are on the increase in Korea (Choi et al, 2002, Korea National Institute of Meteorological Research, 2004; Jung et al, 2010; Choi and Lee, 2013; Choi et al, 2013). First, these results suggest that the hydrologic design criteria of water resource systems for flood event needs to be reformed considering possible risks of extreme events. The importance of designing for heavy rainfall events has been emphasized in many studies (Clark, 1987; Kunkel et al, 1999; Changnon et al, 2000; Kang, 2011). However, it should be carefully considered in local urban plans because the influence of climatological factor varies depending on the regional characteristics in terms of the scales and damage types. Also, water resource system and program cost a lot of money to run. Thus, it seems important for planners and disaster managers to recognize the regional potential risks caused by heavy rainfall events firstly and devise an appropriate regional flood prevention measures. Second, in frequently damaged jurisdictions, decision maker should plan to determine their cause of damage in detail. Those regions need to minimize a recovery time delay and set up a long term solution to be rid of recurring problem. Developing a regular maintenance schedule for floods, collapse, and landslides prone area also can provide benefit to minimize the damage during rainy season.

Third, the floodplain area and steep slope-land variables have different directions. Floodplain area negatively predicts the likelihood of flood property damage, while steep slope-land is positively associated with flood property damage. This result indicates that mountainous areas contain a lot of steep slope-land are more vulnerable to flood risk. This matched Hong and Hwang's (2006) recommendation that flood prevention and mitigation measures in Korea have been excessively focused on the flooding around low-lying areas, thus the damage of mountainous area has been relatively neglected. This finding suggest that decision maker should expand relative importance of managing steep slope area for reducing property damage caused by floods. For example, it is need for damaged area from reclamation and wildfire to take precautions before the rainy season commences. Also, government should try to expand and improve hydro-meteorological monitoring networks in highland watershed.

Fourth, although floodplain area has a negative direction in total model, the effect of floodplain depends on the land-use characteristics. For example, the ratio of impervious area in floodplain area significantly increase the probability of flood damage in urban area during 2000-2004. While, in rural area, it negatively significant with flood damage. Besides, the ratio of farmland in floodplain area positively predicts the odds of flood damage during 10 years (2000-2009) in urban area, but during 2010-2014, it is negatively associated with in recent five years. This result suggests that decision makers in urban area should consider land use characteristics of floodplain area in disaster prevention planning.

Fifth, our results indicate that empty houses do significantly increase flood damage in Korea for 15 years. Additionally, from the urban-rural regression model, we find that this result is only significant in rural area. Even if the number of empty houses are increasing in rural area with the aging population, it is difficult for government to control that because most of empty houses are private property. Many local governments try to solve this problem by supporting maintenance programs for empty houses and policies to utilize as a rental house, but it's simply up to housing owner to participate. Thus, it is necessary to notify about programs and to encourage people to participate. Furthermore, the community and local governmental need to work together to reduce the impact of floods by checking and managing the empty houses.

Limitation

Although this study provides several insights into the relationship between flood property damage and urbanization, natural environmental (hazard and topographical), built environmental, and socioeconomic factors in Korea, there are some limitations as follows:

First, error in the yearbooks of disaster. In yearbooks of disaster which provide disaster damage data as a governmental official material, the damage of buildings is priced based on the same criteria depending on the degree of damage: whole destroyed, partially destroyed, and inundated. Due to the fact that it is not valued its actual price, the result of flood risk assessment can vary if the building damage is aggregated based on its real worth. So, additional flood risk assessment using specific types of property damage seems essential to examine regional characteristics of flood risk in further studies.

Second, flood risk assessment to victims. In this study, we deal with property damages caused by flood in Korea. However, victims including death, missing, injured and inundated people, are also significant factor to understand scale of damage. Besides, the results of risk assessment using victims may be different with the result of this study. Thus it is important to conduct a comprehensive evaluation considering both property damages and victims.

Third, study period. Our study period is limited to fifteen years. It is a bit short to understand a trend of damage. Thus, future study should consider a broader historical time frame though it limits available data.

Fourth, a lack of time-variant characteristics of land use. Our study uses a land cover GIS layer published in 2007 due to the data availability, so there is limit to reflect the specific time-variant characteristics of land use. Future study should include periodic land use data for examining an influence of land use change cause by urbanization on flood damage.

Fifth, ineffective capacity related variables. In this study, capacity related variables are not effective to predict flood property damage. More information regarding non-structural mitigation techniques affecting to the degree of flood damage would help to identify the relationship between capacity related variables and flood property damages.

Ⅵ. Conclusion

We attempted to estimate flood risks considering spatial and temporal variation at the national level. This study is important that it estimated the flood damage at national level. There are few studies analyze flood risks at national level considering temporal variation in Korea. The result of study may help to develop the National action plan on flood damage and arrange budget to support the regional flood prevention methods. Also, this study identified that the effective variables vary depending on the spatial and temporal variation. Although some variables such as precipitation, topographical and socioeconomic variables are highly associated with flood property damages, the directions of them are changed within a temporal context. And the influences of land use variables and socioeconomic variables on flood property damage indicate differently between urban and rural area. Furthermore, the findings of this study provide the evidence that the influcene of urbanization on flood property damage is significant in Korea. It means that floods can be controlled by flood mitigation techniques and efforts though region has a lot of affecting factors to increase flood damages.

From those result, we suggest that both flood risk assessment and flood management should be conducted under the consideration of temporal, structural, and spatial city changes. Setting appropriate regional planning and methodology is important in order to reduce flood property damages. The study may help urban planners and disaster managers to develop regionally appropriate methods for flood damage reduction.

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